UNIT OPERATIONS OF CHEMICAL ENGINEERING

Fourth Edition

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Solving for y_{n+1} gives the operating-line equation, which is the same as that derived earlier for the general case of an equilibrium-stage cascade [Eq. (17-7)]:

$$y_{n+1} = \left(\frac{L_n}{V_{n+1}}\right)x_n + \frac{V_a y_a - L_a x_a}{V_{n+1}} \tag{19-3}$$

As usual, the operating line passes through the points (x_a, y_a) and (x_b, y_b), and if the flow rates are constant, the slope is (L/V).

Constant and variable underflow Two cases are to be considered. If the density and viscosity of the solution change considerably with solute concentration, the solids from the lower-numbered stages may retain more liquid than those from the higher-numbered stages. Then, as shown by Eq. (19-3), the slope of the operating line varies from unit to unit. If, however, the mass of solution retained by the solid is independent of concentration, L_n is constant, and the operating line is straight. This condition is called *constant solution underflow*. If the underflow is constant, so is the overflow. Constant and variable underflow are given separate consideration.

Number of ideal stages for constant underflow When the operating line is straight, a McCabe-Thiele construction can be used to determine the number of ideal stages, but since in leaching the equilibrium line is always straight, Eq. (17-24) can be used directly for constant underflow. The use of this equation is especially simple here because $y_a^* = x_a$ and $y_b^* = x_b$.

Equation (17-24) cannot be used for the entire cascade if L_a, the solution entering with the unextracted solids, differs from L, the underflows within the system. Equations have been derived for this situation,[1,7] but it is easy to calculate, by material balances, the performance of the first stage separately and then to apply Eq. (17-24) to the remaining stages.

Example 19-1 By extraction with kerosene, 2 tons of waxed paper per day is to be dewaxed in a continuous countercurrent extraction system which contains a number of ideal stages. The waxed paper contains, by weight, 25 percent paraffin wax and 75 percent paper pulp. The extracted pulp is put through a dryer to evaporate the kerosene. The pulp, which retains the unextracted wax after evaporation, must not contain over 0.2 lb of wax per 100 lb of wax-free pulp. The kerosene used for the extraction contains 0.05 lb of wax per 100 lb of wax-free kerosene. Experiments show that the pulp retains 2.0 lb of kerosene per pound of kerosene- and wax-free pulp as it is transferred from cell to cell. The extract from the battery is to contain 5 lb of wax per 100 lb of wax-free kerosene. How many stages are required?

SOLUTION Any convenient units may be used in Eq. (17-24) as long as the units are consistent and as long as the overflows and underflows are constant. Thus, mole fractions, mass fractions, or mass of solute per mass of solvent are all permissible choices for concentration. The choice should be made that gives constant underflow. In this problem, since it is the ratio of kerosene to pulp that is constant, flow rates should be expressed in pounds of kerosene. Then, all concentrations must be in pounds of wax per pound of wax-free kerosene. The unextracted paper has no kerosene, so the first cell must be treated separately. Equation (17-24) can then be used for calculating the number of remaining units.